(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
23 March 2006 (23.03.2006)

PCT

(10) International Publication Number
WO 2006/030198 A1

(51) International Patent Classification[7]: H04R 1/40, 3/12

(21) International Application Number: PCT/GB2005/003528

(22) International Filing Date: 13 September 2005 (13.09.2005)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0420240.4 13 September 2004 (13.09.2004) GB

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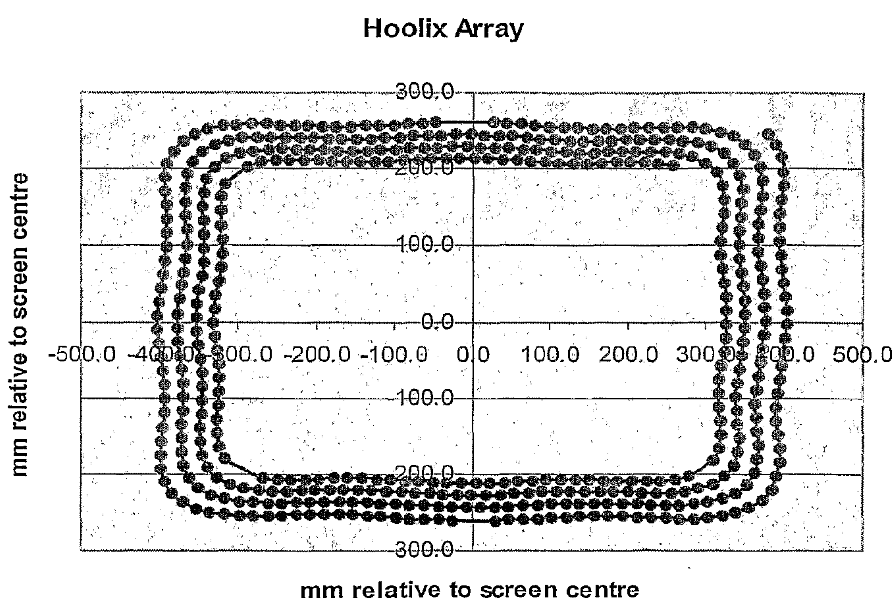
(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: FRAME ARRAY



(57) Abstract: This invention relates to acoustic "phased-array" antennas and their application to single and multi-beam directional loudspeakers and microphones, and more particularly to useful practical forms of said arrays when they have to be confined to the surrounding area of a display screen (such as in a TV or computer display). A method is shown of overcoming the major problems inherent in existing known array forms when disposed around a primarily rectangular screen. The transducers are provided in an irregular formation, such as a spiral formation or a squarised spiral formation.

WO 2006/030198 A1

FRAME ARRAY

The present invention relates to an apparatus for creating a sound field and a method of designing such an apparatus. More particularly, the invention provides a novel arrangement of transducers in an array type loudspeaker which alleviates the problems associated with sidelobes that can occur when sound is beamed in one or more particular directions, especially when the array contains an area devoid of transducers, such as a rectangular area used to support a display screen.

Phased array (and digital-delay array) loudspeakers and microphones are known in the art (see e.g WO01/23104 and WO02/078388), and these include multi-beam arrangements useful for the production of surround sound. The arrays comprise transducers arranged in a regular pattern, such as a square grid pattern or triangular grid pattern. Non-uniformly spaced transducer arrangements are also known, including logarithmic spiral arrays (see e.g.US 5,838,284). However, all of the useful arrays known have an essentially "centrally condensed" transducer layout, by which is meant that the areal density of transducers in the geometric centre of the array is comparable to or most usually greater than the areal density of transducers towards the periphery of the array. Such arrays are therefore not well-suited to be disposed around the edges of a display-screen (as found in TVs and computer & electronic games displays for example). Almost all display screens are rectangular in shape, and indeed if one takes a uniform array, as disclosed in WO01/23104 for example, and simply cuts a rectangular hole in the middle for placement of the screen, in order to allow visibility of said viewing screen, poor beam shape results due to the necessary absence of transducers in the central section of the array.

In the present invention, designs of physical layout of transducer arrays for Digital Delay Array Antennas (DDAA) specifically suitable for disposing about a viewing screen (of nominally rectangular form) are presented and their advantages demonstrated. We do not here discuss the driver electronics and signal processing required to convert the array of transducers into a functional DDAA as these have been adequately described in previous patent applications, and no additional novelty

in that area is required for these new transducer layouts to function correctly and usefully. So it is assumed in what follows that those skilled in the art of DDAA design will understand already the signal processing implications of designing new type DDAAs with these novel transducer layouts.

In a first aspect the invention provides apparatus for creating a sound field, said apparatus comprising: an array of sonic output transducers, which array is capable of directing at least one sound beam in a selected direction; wherein said array surrounds a central region devoid of transducers and suitable for mounting a display screen; and wherein said transducers are disposed in an irregular pattern such that any sidelobes created are at least 3 dB less powerful than the sound beam to be directed.

The irregular pattern of transducers helps to ensure that the vector separating any two transducers is different in both magnitude and angle to a vector separating any other two transducers. When a regular pattern of transducers is used there are many repeated transducer pair spacings which contribute to the creation of a few quite strong sidelobes. The irregular pattern helps to reduce the power of the sidelobes. Preferably, any sidelobes created are at least 5 dB less powerful than the sound beam to be directed and more preferably at least 10 dB less powerful than the sound beam to be directed.

Preferably, the irregular pattern is created according to a mathematical relationship. This assists in designing the apparatus and it helps when modelling the transducer positions. Preferable mathematical relationships include spirals, such as logarithmic spirals. Such spirals are preferably "squarised" by including further mathematical functions that vary with theta such that there are four peaks as theta varies from 0 to 360°. For example, a function based on $\sin^2(2\text{theta})$ is suitable.

In another aspect of the invention, there is provided apparatus for creating a sound field, said apparatus comprising: an array of sonic output transducers, which array is capable of directing at least one sound beam in a selected direction; wherein said

transducers are disposed in a rectangular spiral having horizontal and vertical perturbations in the transducer positions from an ideal rectangular spiral.

The use of a rectangular spiral allows the positions of the transducers to fall outside the area of a rectangular display screen. The horizontal and vertical perturbations in the transducer positions from an ideal rectangular spiral creates a certain degree of irregularity in the pattern which helps to minimise the power of sidelobes which can be created in use of the device. The use of a rectangular spiral with perturbation alleviates the creation of powerful sidelobes, even in arrays not having a central area devoid of transducers. However, the invention is clearly also of use in the case that a substantially rectangular display screen needs to be surrounded by transducers.

A third aspect of the invention also provides apparatus for creating a sound field, said apparatus comprising: an array of sonic output transducers, which array is capable of directing at least one sound beam in a selected direction; wherein said array surrounds a central region devoid of transducers and suitable for mounting a display screen; and wherein said transducers are disposed in a spiral around said central region.

The use of a spiral transducer position, rather than a regular grid transducer position, alleviates somewhat the problems with powerful sidelobes being inadvertently or accidently created. Even better performance can be obtained by ensuring that the inter-transducer spacing, measured along the line of the spiral itself, is irregular.

The invention provides in a fourth aspect a method of designing a sonic transducer array, said method comprising: determining a display screen area; defining a spiral curve around said display screen area upon which transducers may be placed such that said transducers do not mechanically interfere with each other or a display screen when the same is placed in said display screen area; determining the positions of each transducer along said spiral curve.

The use of a spiral curve in designing the transducer array allows the transducers to, on the one hand, be located in a fairly dense grouping around the periphery of the display screen (thereby ensuring that the overall apparatus size is not too large), and, on the other hand, helps to avoid a regular grid pattern being provided which can cause the creation of deleterious sidelobes.

It assists in designing the array if the curve is defined using a mathematical relationship.

As well as a method of designing the array, the invention also includes a method of creating a sound field in which at least one sound beam is directed using an array of sonic output transducers, the output transducers being positioned such that any sidelobes created are at least 3 dB less powerful than the sound beam to be directed. Preferably the apparatus comprises a central region devoid of transducers. The irregular pattern is preferably a spiral and more preferably a squarised spiral.

Before describing the invention in detail with reference to preferred embodiments, several definitions of terms are given to aid in understanding the invention.

Definitions

The "Hoolix": The term "Hoolix" is coined to refer to a family of curves that have some of the properties of squares (or more generally rectangles) and some of the properties of spirals. A square or rectangular "curve" is a closed loop that has four straight-line segment sides in two parallel pairs (with each segment of a parallel pair having equal length, and the segments in each pair being orthogonal to the segments in the other pair, and for the square as opposed to rectangle case, the lengths of segments in each pair are also identical to each other). Also included within the definition of Hoolix such parallel pairs of line segments where the orthogonality constraint is dropped (in which case the forms of the loops are what are colloquially called "diamonds" and technically parallelograms).

A spiral curve is (except in the limiting case) here defined as a non-closed-loop curve which, with the increase of some parameter t, takes successively increasing or decreasing values of polar angular coordinate theta about some origin O and which takes successively increasing or decreasing values of radial coordinate r from that same origin O. The particular nature of the functional relationship between r, theta and t determines the exact form of said spiral. In Simple Spirals, the increase or decrease of r and theta with t are both monotonic. Complex Spirals are defined as otherwise similarly defined curves, wherein the increase or decrease of r and theta with t are non-monotonic, but nonetheless where for each increase of theta by 2pi radians, the related increase or decrease of theta integrated over that 2pi range of theta is monotonic. Thus, Complex Spirals generally grow or shrink in radius with gross changes in theta but may also have "wiggles". Common forms of Simple Spirals are the linear spiral, Slin(t):

theta(t) = k1*t; [polar angle of Slin(t) as a function of t]
r(t) = k2*t; [polar radius of Slin(t) as a function of t]
[here "*" represents multiplication]

where k1 and k2 are constants;

and the logarithmic spiral, Slog(t):

theta(t) = k1*t;
r(t) = k2*exp(k3*t);

where the radius is no longer a simple linear function of t and thus of theta, but is nonetheless monotonic as defined above.

However, any curve which meets the above definition of Simple or Complex Spiral is included within the following definition of a Hoolix.

Combining these two sets of properties (squares and spirals) a general Hoolix is defined as any curve that meets the definition of Simple or Complex Spiral as given above, and which simultaneously has the property that certain contiguous sections of the curve opposite to each other with respect to the origin of the curve O, are approximately straight and approximately parallel, insofar as curves (rather than

straight lines) may be said to be "parallel" at all. For clarity, below a definition of "approximately straight" and of "approximately parallel" is given. A more specialised form of Hoolix, the Parallelogram Hoolix, has just two pairs of such opposite approximately-parallel sections per (approximately) 2pi radian increase in theta. An even more specialised form of Hoolix, the Rectangular Hoolix, is a form of Parallelogram Hoolix where adjacent (connected) approximately straight sections of the curve are approximately at right angles to each other. Finally a more specialised form of Rectangular Hoolix, the Square Hoolix has such adjacent approximately straight sections of the curve, also of approximately the same length as each other, giving the curve a squarish spiral shape.

"Approximately Straight": A section of a continuous curve C(t), Cx = Fx(t), Cy = Fy(t), from point A = C(t1) at t = t1 to point B = C(t2) at t = t2 = t1 +2dt, is "Approximately Straight" if it meets the following criterion:

The curve between A & B may be entirely contained within a rectangular boundary passing through A and B, where the aspect ratio of said rectangle is more than 3:1, or preferably more than 5:1, or more preferably still, more than 10:1. In general there will be just one smallest possible bounding rectangle completely enclosing the curve between A & B [smallest in area] and the angular position of the longer side of said smallest bounding rectangle is then said to be the "slope-direction" of the curve segment between A & B.

"Approximately Parallel": Two sections C1(t) and C2(t) of continuous curves are said to be "Approximately Parallel" if their slope-directions are within 30deg of each other, or preferably within 15deg of each other or more preferably within 5deg of each other.

"Approximately at Right Angles": Two sections C1(t) and C2(t) of continuous curves are said to be "Approximately at Right Angles" if their slope-directions are within 90deg plus or minus 30deg from each other, or preferably are within 90deg plus or minus 15deg each other or more preferably are within 90deg plus or minus

5deg each other.

The invention will now be further described by way of non-limitative example only, with reference to the accompanying drawings, in which:-

Fig. 1 shows an array of transducers that might be obtained if a standard regular pattern of prior art transducers is modified so as to provide a central area devoid of transducers for the mounting of the display screen;
Fig. 2 shows an array of transducers laid out along a Hoolix curve according to one aspect of the present invention;
Fig. 3 shows some functions that can be used to create a Hoolix curve;
Fig. 4 shows a plan view of the beam shape obtained when the array of Fig. 2 is used, at 10 kHz;
Fig. 5 shows a 2π radian beam plot for the same Hoolix array and frequency as Fig. 4;
Fig. 6 is similar to Fig. 4 but is for a uniform rectangular array with a hole in the middle, similar to that shown in Fig. 1; and
Fig. 7 is similar to Fig. 5, but shows a 2π radian beam plot for a uniform rectangular array having a hole in the centre.

Consider a modern liquid crystal display (LCD) monitor or TV, typically of about 61 cm (24 inches) diagonal size, and a few centimetres thick. With the physical structure required around the screen for mounting and protection, such an LCD monitor (hereinafter simply LCD) is perhaps 61 cm (24 inches) wide by 36 cm (14 inches) high. If it was desired to place this LCD in the middle of a conventional regularly spaced DDAA (which could be used as the surround sound audio system associated with the LCD video screen) then there would necessarily be a hole in the DDAA (where the LCD was) at least 61 cm x 36 cm. 61 cm is the wavelength of sound of frequency ~550Hz and 36 cm the wavelength of sound of frequency ~940Hz. Because of the hole in the DDAA the sections of antenna either side of the screen (formed by the adjacent array of transducers there) would form an interferometer at frequencies above ~ 550Hz, and thus, were the DDAA to be used as a transmission

antenna, then full power aliases in the horizontal plane would be expected at many frequencies higher than ~550Hz within the audible band, which would greatly detract from the functionality of the DDAA for surround sound purposes. Similar alias beam problems in the vertical plane would be produced by the hole, above a frequency of ~940Hz. The apparatus proposed in Fig. 1 suffers from such a problem. This apparatus is rectangular and has a central rectangular screen measuring 61 cm x 36 cm. There are 480 transducers in all, each transducer having a diameter of 13 mm with a centre to centre spacing of about 18 mm. The transducers are disposed in a regular square grid pattern.

The present invention proposes to reduce these problems by positioning the transducers forming the DDAA around the LCD screen, not in a regular grid pattern, but instead, laying them down in an irregular pattern. For example in a spiral pattern or at successive positions along a carefully designed Rectangular Hoolix curve (defined above). Said Hoolix curve is designed to have a starting point >~ one transducer radius from a point on the outer edge of the LCD screen (and more usefully perhaps near a corner of said screen) and then proceeds in a clockwise or anticlockwise fashion around said screen such that its first Hoolix turn (by analogy with a first spiral turn) (i.e. its geometric trajectory with, say, increasing parameter t) closely follows the border of the screen, but at all or nearly all points remains greater than one transducer radius from the screen edge. Thus transducers may be positioned along said Hoolix trajectory without mechanically interfering with the LCD screen structure. By the time the Hoolix curve has completed one revolution of the screen, it is designed to now be >~1 transducer diameter greater in radial distance from the screen centre than at its starting point, so that successive transducers laid out along its trajectory now do not interfere with those laid out along the first turn.

The two predominantly straight and parallel pairs of "sides" of the Hoolix are designed to be approximately parallel to the two sets of parallel edges of the LCD screen. More and more Hoolix turns may then be "wrapped" around the screen, with gradually increasing polar radii, transducers being laid along the curve as before, such that none of the transducers mechanically interfere with any others, or with the

LCD screen structure. Typically two to four Hoolix turns of transducers will suffice to produce a useful DDAA. As to how to lay out the transducers along the Hoolix trajectory: a simple and useful strategy is to place a first transducer at the Hoolix starting point as described above, and thereafter to place successive transducers an approximately fixed distance from the previous one, as measured along the Hoolix curve/trajectory. The value of this ~fixed distance is a free parameter but again, typically, a useful value is one to two transducer diameters, although greater spacings also work usefully. Smaller spacings would necessarily produce mechanical interference between adjacent transducers. However, non-fixed or irregular transducer-transducer spacings are also useful, particularly spacings that increase slowly with successive distance along the Hoolix trajectory from the inner starting point, so that the outer "ring" of transducers has greater inter-transducer spacing than the inner ring of transducers. As the Hoolix turns can also have successively greater turn-to-turn spacing (if for example the Hoolix is not of the simple linear Hoolix form) then the two successively increasing transducer spacing parameters (i.e. along the curve and between turns of the curve) allow for the use of larger transducers towards the outside of the Hoolix DDAA which are generally better for the reproduction of lower frequencies.

The transducers themselves are preferably chosen so that they have the desired audio bandwidth, and, are preferably of a diameter such that they are reasonably non-directional over the frequencies of interest for controlling by the DDAA. These requirements usually imply that the transducer diameters are smaller than an acoustic wavelength (in air or the DDAA working fluid) at, at least, half the maximum operating frequency of the transducers in the DDAA (NB not all said transducers necessarily operate over the whole DDAA bandwidth, and there are specific advantages to be had by giving greater emphasis to lower frequencies towards the outside transducers of the Hoolix and greater emphasis to the higher frequencies towards the inner transducers of the Hoolix). So, e.g. for a hi-fi surround system for use with a TV or computer monitor, the maximum frequency of interest would probably lie in the region from 16KHz to 20KHz, implying an acoustic wavelength of half these frequencies, i.e. 43mm to 17mm, and thus transducer diameters, (at least

those transducers in the high-frequency region of the DDAA array which are preferably positioned closest to the LCD screen edge), within this range or smaller.

A particular form of DDAA designed along these lines is shown in Fig. 2. It has 480 transducers of diameter 13mm distributed along such a Hoolix curve at centre to centre spacing distance of ~18mm. The positions of the points plotted correspond to the (x, y) coordinates given Table 1 below. The transducers are driven in adjacent pairs (adjacent along the Hoolix curve trajectory) for a total of 240 driver amplifiers (to reduce cost and complexity). The actual transducer centre coordinates used for this specific DDAA are shown in Table 1 annexed to the end of the description, where each triplet of columns represents; i) a transducer reference number, 1 to 480; ii) a transducer x-coordinate in mm (chosen to be a horizontal position, i.e. the direction parallel to the long edge of the LCD screen used); and iii) a transducer y-coordinate in mm. Thus the first three columns show the positions of the first 60 transducers, the next three columns the positions of the next 60 transducers, and so on for a total of 480 transducers. Inspection of the coordinates will show that there are some gaps in a continuous evenly spaced set of transducer positions along the chosen Hoolix curve. These gaps are where transducers have been omitted from the DDAA because the position of such transducers would have caused them to mechanically interfere either with the LCD screen on the inside of the DDAA, or the outside casing of the DDAA, designed to be rectangular and approximately parallel to the LCD screen, and as compact as possible. Such omitted transducers, if small in number, from the otherwise continuous array cause only small imperfections in the DDAA beam shape and are not a problem, and this flexibility in choice of actual transducer locations is very helpful when designing real arrays with specific functional or product requirements.

Plotting of the presented coordinates, as has been done in Fig. 2, will show that there is a large blank area within the layout of transducers, quite large enough to house a commercially available 61 cm (24 inch) LCD computer monitor screen. The performance of this DDAA array exemplified by the coordinate table below, has been computer modelled and verified experimentally and found to behave

extraordinarily well as a single-box surround sound DDAA system. A woofer, positioned in a long thin box beneath the screen and DDAA, was used to reproduce frequencies below ~300Hz because of the low-frequency limitations of the 13mm transducers used in the array - however, the latter perform extremely well up to the highest audible frequencies and are exceptionally omnidirectional (in a half space) because of their small diameter.

The analytical form of the particular Hoolix curve used for the DDAA just described is:

```
    x := radx*exp(b*(theta+th0))*(1+sqrn*exp(-gg*(1-sqrt(sin(2*theta)))))*
cos(theta+th0);
    y := rady*exp(b*(theta+th0))*(1+sqrn*exp(-gg*(1-sqrt(sin(2*theta))))) *
sin(theta+th0);
```

where:
(x, y) are the coordinates of a point along the Hoolix trajectory;
theta is the polar angle of the curve; this is the parameter that successively increases or decreases as one follows the trajectory of the curve;
radx and rady are characteristic dimensions of the curve in the directions of the X-axis and Y-axis respectively, so that the curve may have any desired aspect ratio, and thus be matched to, for example, a 16:9 display screen;
b and th0 are a pair of parameters analogous to those found in the simple logarithmic spiral curve and are related to the scale of the curve and its starting angle;
sqrn is a parameter, 0 <sqrn<=1.0, which determines the "squareness" of the Hoolix curve, with sqrn = 0 leaving the curve a pure spiral with no squareness, and sqrn = 1.0 producing a Hoolix with high squareness;
gg is another scaling parameter relating to the amount of squareness produced;
sqrt() is the square root function;

The remarkable thing about the DDAA just described, and about all such properly designed DDAAs using irregular patterns such as spiral curve or Hoolix curve

geometry, is that despite the transducer array having a large "hole" in it, wherein sits the display screen, the alias beam-performance and sidelobe-performance are good, and exceptionally good in the case of the Hoolix curve, and certainly more than adequate for most multi-beam sound systems.

The principal feature of the above described irregular transducer layouts for DDAAs, is that the resulting set of transducer positions does not result in many or any identical transducer-pair spacings and angular orientations. By this is meant that if one takes each transducer in turn, and pairs it with each and every other transducer in the array, the set of all spacing and relative angular directions of such pairs will form a smooth distribution with few if any peaks. Compare this with the situation if the transducers were laid out in a regular rectangular or triangular array with a hole in it (e.g. a hole large enough to place a plasma or LCD screen of say 24 inches or more). Because of the regular transducer position grid in these cases the distribution of all pairings would have many distinct and strong peaks in it. The effect of the smooth distribution in the irregular (e.g. Hoolix) case is to produce only (many) weak sidelobes; and in the case of the peaky distribution of the regular array, to produce a few very strong sidelobes. So use of the Hoolix layout produces a sharp main beam surrounded by a broad but low floor of weak sidelobes, with no strong sidelobes present, which is unattainable with a regular array surrounding a hole.

A regular rectangular spiral arrangement where the transducers are all equispaced along a set of orthogonal straight lines surrounding the hole in the array offers some improvement over a regular array but can still produce sidelobes which lower the usability of the arrangement as a DDAA array for some applications. An improvement over the regular rectangular spiral can be achieved by using non-constant transducer spacing (along the square-spiral) and by using non-constant square-turn spacing – these measures flatten out somewhat the distribution of transducer pair spacings. However, the fact that many transducers still share the same horizontal and/or vertical coordinates (because of the rectangular layout) means that the sidelobes produced by each pair tend to stack up along particular directions. This effect is further reduced by applying horizontal and/or vertical perturbations to the

"ideal" positions in the square spiral. By doing this, an arrangement similar to the Hoolix curve in Fig. 2 is achieved.

Fig. 3 shows the mathematical development of a particular Hoolix curve. The basis form is the Circle. Various "Squarising" functions are also shown, including; Sq1 = SQRT(radx*rady)*SIN(2*theta)^2, and Sq2 = (SQRT(radx*rady)*SIN(2*theta)^2)^2, and Sq3 = EXP(-gg*(1-(SIN(2*theta)^2))) [this function labelled "Gauss" in Fig. 2], where "^" means raised to the power, "*" denotes multiplication, "SQRT" denotes square root, and "theta" is the polar angle of the function. "gg" is a free parameter which determines the degree of Squarising. A fourth Squarising function Sq4 is also shown. Labelled "sqf" in Fig. 3, and this is a linear combination of Sq1, Sq2 and Sq3 of the form sqf=aa*Sq1+ab*Sq2+ac*Sq3, where aa, ab, and ac are free parameters, usefully in the range 0 to 1.0. The Circle is "Squarised" by multiplying its normally fixed radius r by one of the Squarising functions, with radx = rady = r. An Ellipse can similarly be squarised, by multiplying its radius (already a function of theta) by a Squarising function. Finally, Fig. 3 shows a Hoolix curve, in this case produced from a basis curve which is a logarithmic spiral, but again where its radius, already a function of theta, is multiplied by a Squarising function, in the case illustrated, Sq3 (Gauss) being used.

Fig. 4 shows a plan view of the beam shape of a Hoolix array, at 10KHz, where the array is at bottom centre of the figure. The Figure represents an 8m square area in front of the array. In this plot the beam is focussed at a point 3m away directly in front of the array (above in the picture), so focussed nearly at the centre of the array. The amplitude scale is shown on band at the RHS of the plot, the colour/shading at the top of the band representing 0dB, that at the bottom -50dB. A strong well focussed beam is evident with sidelobes lower than 15dB to 20dB down.

Fig. 5 shows a 2pi radian beam plot (akin to a Mercator Map projection), for the same Hoolix array and frequency as Fig. 4. The beam is again focussed at 3m from the array. The horizontal centre line of the plot represents longitudinal angles from -90 to +90 degrees, at zero latitude. The vertical centre line represents latitudinal

angles from +90deg through 0deg at plot centre to -90deg, at zero longitude. The N and S poles are spread right along the top and bottom of the plot respectively. The amplitude scale is again shown by the band at the RHS with 0dB at the top and -20dB at the bottom. Where the plot is white the amplitude is more than -20dB down. There is clearly a well focussed central beam with marginal sidelobes, even at 10KHz.

Fig. 6 is directly comparable with Fig. 4 but is for a uniform rectangular array with a hole in the middle, similar to that shown in Fig. 1. While a strongly focussed beam is visible, there are clearly very many strong sidelobes (principally due to the hole in the middle of the array) making this simple approach useless for most applications.

Fig. 7 is directly comparable with Fig. 5 but is again for the uniform rectangular array. What now becomes apparent is that the strong sidelobe pattern for this simple array extends in both vertical and horizontal directions.

Ref No.	x [mm]	y [mm]	Ref No.	x [mm]	y [mm]	Ref No.	x [mm]	y [mm]	Ref No.	x [mm]	y [mm]	Ref No.	x [mm]	y [mm]	Ref No.	x [mm]	y [mm]	Ref No.	x [mm]	y [mm]	Ref No.	x [mm]	y [mm]
1	258.37	203.9	61	-122.6	-206.2	121	29.593	227.82	181	-18.37	-227.44	241	15.988	244.12	301	-79.65	-240.69	361	154.7	253.2	421	-243.9	-254.23
2	240.43	207.4	62	-104.4	-207.2	122	11.341	228.55	182	-0.098	-227.62	242	-2.275	244.54	302	-61.43	-241.9	362	136.5	253.7	422	-225.7	-253.58
3	222.24	208.9	63	-86.16	-208.5	123	-6.923	228.88	183	18.171	-227.41	243	-20.55	244.57	303	-43.18	-242.87	363	118.2	254.6	423	-207.4	-253.02
4	203.97	209.3	64	-67.94	-209.8	124	-25.19	228.81	184	36.431	-226.83	244	-38.81	244.24	304	-24.93	-243.54	364	100	255.8	424	-189.2	-252.74
5	185.72	208.9	65	-49.71	-211	125	-43.45	228.35	185	54.672	-225.96	245	-57.06	243.57	305	-6.666	-243.84	365	81.78	257.1	425	-170.9	-252.85
6	167.46	208.2	66	-31.46	-211.9	126	-61.7	227.56	186	72.905	-224.92	246	-75.31	242.64	306	11.596	-243.78	366	63.56	258.4	426	-152.6	-253.4
7	149.21	207.7	67	-13.2	-212.4	127	-79.93	226.54	187	91.138	-223.84	247	-93.55	241.57	307	29.86	-243.37	367	45.33	259.6	427	-134.4	-254.33
8	130.94	207.5	68	5.0588	-212.4	128	-98.17	225.46	188	109.38	-222.92	248	-111.8	240.51	308	48.111	-242.64	368	27.09	260.5	428	-116.2	-255.54
9	112.67	207.9	69	23.318	-212.1	129	-116.4	224.5	189	127.63	-222.35	249	-130	239.64	309	66.353	-241.68	369	-45.95	260.9	429	-97.95	-256.88
10	94.427	208.7	70	41.573	-211.4	130	-134.7	223.86	190	145.9	-222.23	250	-148.3	239.11	310	84.592	-240.6	370	-64.19	260.1	430	-79.73	-258.19
11	76.2	209.9	71	59.817	-210.4	131	-152.9	223.68	191	164.16	-222.56	251	-166.6	239.03	311	102.83	-239.55	371	-82.44	259.2	431	-61.51	-259.36
12	57.979	211.3	72	78.051	-209.3	132	-171.2	223.98	192	182.41	-223.25	252	-184.8	239.4	312	121.07	-238.69	372	-100.7	258.1	432	-43.27	-260.29
13	39.755	212.5	73	96.291	-208.3	133	-189.5	224.65	193	200.65	-224.08	253	-203.1	240.09	313	139.33	-238.18	373	-118.9	257	433	-25.02	-260.92
14	21.512	213.5	74	114.55	-207.6	134	-207.7	225.47	194	218.9	-224.79	254	-221.3	240.92	314	157.59	-238.1	374	-137.2	256.2	434	29.774	-260.79
15	3.252	214.1	75	132.81	-207.4	135	-226	226.19	195	237.17	-225.1	255	-239.6	241.65	315	175.85	-238.44	375	-155.4	255.6	435	48.031	-260.12
16	-15.02	214.2	76	151.08	-207.7	136	-244.2	226.47	196	255.43	-224.66	256	-257.8	242	316	194.1	-239.12	376	-173.7	255.4	436	66.271	-259.2
17	-33.28	213.9	77	169.34	-208.3	137	-262.5	225.94	197	273.62	-223.03	257	-276.1	241.66	317	212.34	-239.94	377	-191.9	255.7	437	84.511	-258.14
18	-51.53	213.3	78	187.59	-209.2	138	-280.7	224.13	198	291.56	-219.6	258	-294.3	240.23	318	230.59	-240.7	378	-210.2	256.3	438	102.75	-257.06
19	-69.77	212.3	79	205.84	-209.8	139	-298.5	220.35	199	308.77	-213.48	259	-312.3	237.17	319	248.85	-241.14	379	-228.5	257.1	439	120.99	-256.1
20	-88.01	211.3	80	224.1	-210.1	140	-315.5	213.6	200	324.08	-203.51	260	-329.7	231.7	320	267.12	-240.98	380	-246.7	257.9	440	139.25	-255.4
21	-106.2	210.3	81	242.35	-209.4	141	-330.1	202.64	201	335.34	-189.13	261	-345.7	222.78	321	285.34	-239.85	381	-265	258.5	441	157.51	-255.07
22	-124.5	209.6	82	260.51	-207.4	142	-340	187.29	202	341.11	-171.8	262	-358.3	209.56	322	303.42	-237.31	382	-283.2	258.6	442	175.78	-255.15
23	-142.8	209.3	83	278.27	-203.1	143	-344.3	169.54	203	342.52	-153.59	263	-365.7	192.89	323	321.1	-232.69	383	-301.5	257.9	443	194.03	-255.62
24	-161	209.6	84	308.52	-183.4	144	-344.8	151.28	204	341.64	-135.34	264	-368.4	174.81	324	337.7	-225.07	384	-319.7	256	444	212.29	-256.35
25	-179.3	210.3	85	316.74	-167.1	145	-343.5	133.06	205	340.19	-117.13	265	-368.2	156.55	325	351.82	-213.49	385	-337.6	252.5	445	230.53	-257.18
26	-197.5	211.2	86	319.55	-149	146	-342.2	114.84	206	339.53	-98.874	266	-366.7	138.34	326	361.49	-197.99	386	-354.8	246.5	446	248.78	-257.92
27	-215.8	211.8	87	319.17	-130.7	147	-342.2	96.573	207	340.45	-80.632	267	-365.6	120.11	327	366.07	-180.31	387	-370.5	237.2	447	267.05	-258.34
28	-234	211.9	88	317.73	-112.5	148	-343.9	78.382	208	342.83	-62.524	268	-365.7	101.84	328	366.95	-162.06	388	-382.9	223.8	448	285.31	-258.18
29	-252.3	211	89	316.87	-94.29	149	-346.7	60.332	209	345.85	-44.509	269	-367.4	83.657	329	365.93	-143.82	389	-390.5	207.2	449	303.55	-257.16
30	-270.4	206.4	90	317.64	-76.04	150	-349.7	42.31	210	348.6	-26.453	270	-370.2	65.604	330	364.49	-125.62	390	-393.6	189.2	450	321.68	-254.86
31	-287.9	203.4	91	319.99	-57.92	151	-351.9	24.186	211	350.43	-8.2799	271	-373.2	47.584	331	363.78	-107.36	391	-393.6	170.9	451	339.48	-250.75
32	-315.7	180.5	92	323	-39.91	152	-353	5.9553	212	351	9.9793	272	-375.7	29.484	332	364.54	-89.113	392	-392.3	152.7	452	356.48	-244.08
33	-321.6	163.2	93	325.67	-21.84	153	-352.8	-12.31	213	350.24	28.231	273	-377.1	11.269	333	366.73	-70.976	393	-391	134.4	453	371.68	-233.96
34	-322.8	145	94	327.28	-3.649	154	-351.2	-30.51	214	348.38	46.403	274	-377.2	-6.999	334	369.69	-52.955	394	-390.6	116.2	454	383.38	-219.93
35	-321.7	126.8	95	327.5	14.614	155	-348.9	-48.62	215	345.95	64.508	275	-376.1	-25.23	335	372.6	-34.926	395	-391.6	97.95	455	390.3	-203.03
36	-320.4	108.5	96	326.35	32.842	156	-346.5	-66.74	216	343.75	82.643	276	-374	-43.37	336	374.82	-16.799	396	-394	79.84	456	392.94	-184.95
37	-320.3	90.27	97	324.19	50.981	157	-345.2	-84.95	217	342.69	100.88	277	-371.6	-61.47	337	375.95	1.4344	397	-397	61.82	457	392.87	-166.68
38	-322	72.09	98	321.75	69.082	158	-345.4	-103.2	218	343.19	119.14	278	-369.5	-79.63	338	375.83	19.701	398	-399.9	43.78	458	391.56	-148.46
39	-324.9	54.06	99	320.07	87.269	159	-346.9	-121.4	219	344.86	137.33	279	-368.7	-97.87	339	374.54	37.921	399	-402	25.64	459	390.2	-130.25
40	-327.8	36.02	100	319.96	105.54	160	-348.7	-139.6	220	346.61	155.51	280	-369.4	-116.1	340	372.38	56.055	400	-403.1	7.41	460	389.74	-111.99
41	-329.8	17.87	101	321.34	123.75	161	-349.3	-157.8	221	347	173.78	281	-371.1	-134.3	341	369.92	74.155	401	-403	-10.9	461	390.71	-93.75
42	-330.5	-0.382	102	323.18	141.92	162	-346.7	-175.9	222	344.18	191.83	282	-372.8	-152.5	342	367.92	92.315	402	-401.8	-29.1	462	392.98	-75.622
43	-329.6	-18.63	103	323.93	160.17	163	-338.9	-192.5	223	336.29	208.3	283	-373.2	-170.8	343	367.13	110.56	403	-399.6	-47.2	463	395.94	-57.598
44	-327.7	-36.79	104	321.58	178.28	164	-325.8	-205.2	224	323.22	221.05	284	-370.4	-188.8	344	367.82	128.82	404	-397.2	-65.3	464	398.89	-39.575
45	-325.2	-54.89	105	313.92	194.87	165	-309.5	-213.4	225	307.03	229.49	285	-362.7	-205.4	345	369.52	147	405	-395.1	-83.5	465	401.23	-21.46
46	-323.3	-73.06	106	300.73	207.5	166	-291.9	-218.3	226	289.48	234.57	286	-350	-218.5	346	371.29	165.19	406	-394	-102	466	402.59	-3.2493
47	-323	-91.32	107	284.34	215.57	167	-273.8	-220.9	227	271.42	237.37	287	-334	-227.4	347	371.85	183.44	407	-394.4	-120	467	402.8	15.016
48	-324.3	-109.5	108	266.67	220.21	168	-255.6	-222	228	253.2	238.64	288	-316.6	-232.8	348	369.64	201.57	408	-396	-138	468	401.87	33.258
49	-326.1	-127.7	109	248.56	222.59	169	-237.3	-222.1	229	234.94	238.91	289	-298.6	-236	349	362.93	218.56	409	-397.8	-156	469	399.99	51.431
50	-326.9	-146	110	230.31	223.5	170	-219.1	-221.7	230	216.68	238.58	290	-280.4	-237.5	350	351.12	232.51	410	-398.9	-175	470	397.58	69.535
51	-324.5	-164.1	111	212.04	223.5	171	-200.8	-221	231	198.41	237.96	291	-262.1	-238	351	335.73	242.34	411	-397.8	-193	471	395.23	87.647
52	-316.5	-180.5	112	193.78	223.01	172	-182.5	-220.5	232	180.16	237.34	292	-243.9	-237.8	352	318.68	248.64	412	-393	-210	472	393.65	105.85
53	-268.6	-204.6	113	175.53	222.36	173	-164.3	-220.2	233	161.9	236.96	293	-225.6	-237.2	353	300.7	252.4	413	-383.1	-226	473	393.38	124.11
54	-250.4	-206.6	114	157.27	221.85	174	-146	-220.4	234	143.64	236.98	294	-207.4	-236.6	354	282.55	254.41	414	-369.1	-237	474	394.43	142.35
55	-232.2	-207.3	115	139.01	221.72	175	-127.8	-221.1	235	125.38	237.48	295	-189.1	-236.1	355	264.29	255.23	415	-352.6	-245	475	396.25	160.52
56	-213.9	-207.1	116	120.74	222.1	176	-109.5	-222.1	236	107.14	238.42	296	-170.8	-235.9	356	246.03	255.26	416	-335	-250	476	397.92	178.71
57	-195.7	-206.5	117	102.49	222.95	177	-91.3	-223.4	237	88.912	239.65	297	-152.6	-236.2	357	227.76	254.82	417	-316.9	-253	477	398.33	196.97
58	-177.4	-205.9	118	84.267	224.16	178	-73.09	-224.8	238	70.699	240.99	298	-134.3	-236.9	358	209.51	254.18	418	-298.7	-254	478	396.06	215.1
59	-159.1	-205.5	119	66.052	225.49	179	-54.87	-226	239	52.479	242.27	299	-116.1	-238	359	191.26	253.58	419	-280.5	-255	479	389.59	232.18
60	-140.9	-205.6	120	47.827	226.77	180	-36.63	-226.9	240	34.242	243.34	300	-97.86	-239.4	360	172.99	253.22	420	-262.2	-255	480	378.32	246.55

Table 1: Transducer positions as shown in Figure 2

CLAIMS

1. Apparatus for creating a sound field, said apparatus comprising:

an array of sonic output transducers, which array is capable of directing at least one sound beam in a selected direction;

wherein said array surrounds a central region devoid of transducers and suitable for mounting a display screen; and

wherein said transducers are disposed in an irregular pattern such that any sidelobes created are at least 3 dB less powerful than the sound beam to be directed.

2. Apparatus according to claim 1, wherein said irregular pattern is created according to a mathematical relationship.

3. Apparatus according to claim 2, wherein said mathematical relationship is a logarithmic spiral that has been squarised by sine or cosine functions.

4. Apparatus for creating a sound field, said apparatus comprising:

an array of sonic output transducers, which array is capable of directing at least one sound beam in a selected direction;

wherein said transducers are disposed in a rectangular spiral having horizontal and vertical perturbations in the transducer positions from an ideal rectangular spiral.

5. Apparatus according to claim 4, wherein said array surrounds a central region devoid of transducers and suitable for mounting a display screen.

6. Apparatus for creating a sound field, said apparatus comprising:

an array of sonic output transducers, which array is capable of directing at least one sound beam in a selected direction;

wherein said array surrounds a central region devoid of transducers and suitable for mounting a display screen; and

wherein said transducers are disposed in a spiral around said central region.

7. Apparatus according to any one of claims 3 to 6, wherein transducers are laid out along said spiral path with an irregular inter-transducer spacing along the line of said spiral.

8. Apparatus according to any one of the preceding claims, wherein it is arranged such that said at least one sound beam is created using substantially all the transducers in the array.

9. Apparatus according to any one of the preceding claims, wherein said central region devoid of transducers is substantially rectangular.

10. An audio-visual device including a display screen and an apparatus for creating a sound field according to any one of the preceding claims.

11. An audio-visual device according to claim 10, wherein said audio-visual device is a television.

12. An audio-visual device according to claim 10, wherein said audio-visual device is a computer monitor.

13. A method of designing a sonic transducer array, said method comprising:

determining a display screen area;

defining a spiral curve around said display screen area upon which transducers may be placed such that said transducers do not mechanically interfere with each other or a display screen when the same is placed in said display screen area;

determining the positions of each transducer along said spiral curve.

14. A method according to claim 10, wherein said curve is defined using a mathematical relationship.

15. A method according to claim 11, wherein said curve is a squarised spiral.

16. A method according to any one of claims 10 to 12, wherein said curve and said positions along the curve are determined such that any sidelobes created are at least 3 dB less powerful than the sound beam to be directed.

FIG. 1.

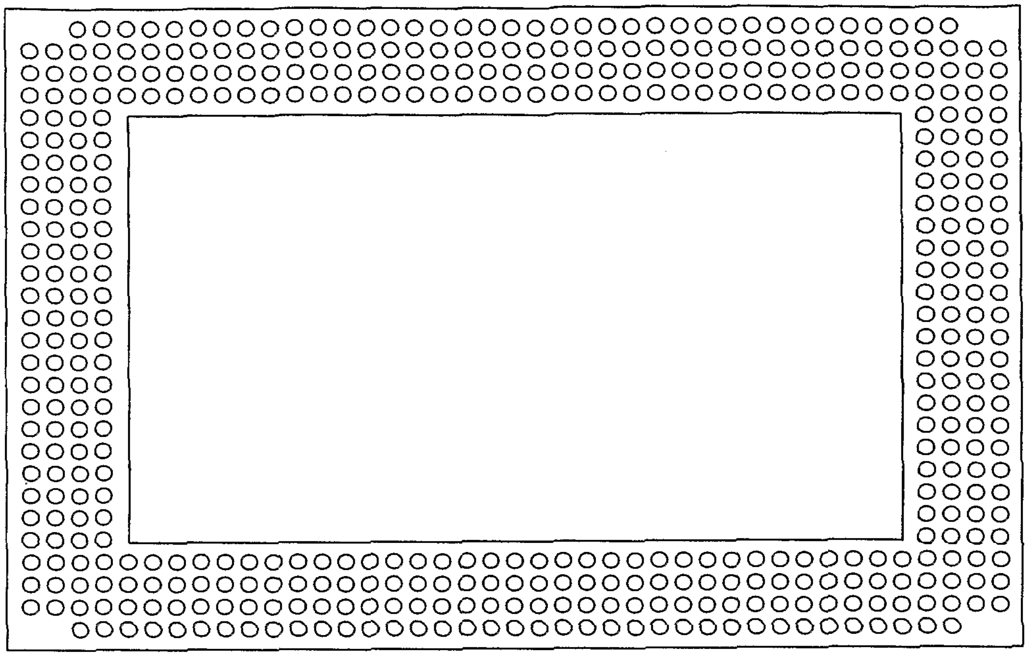


FIG. 2.

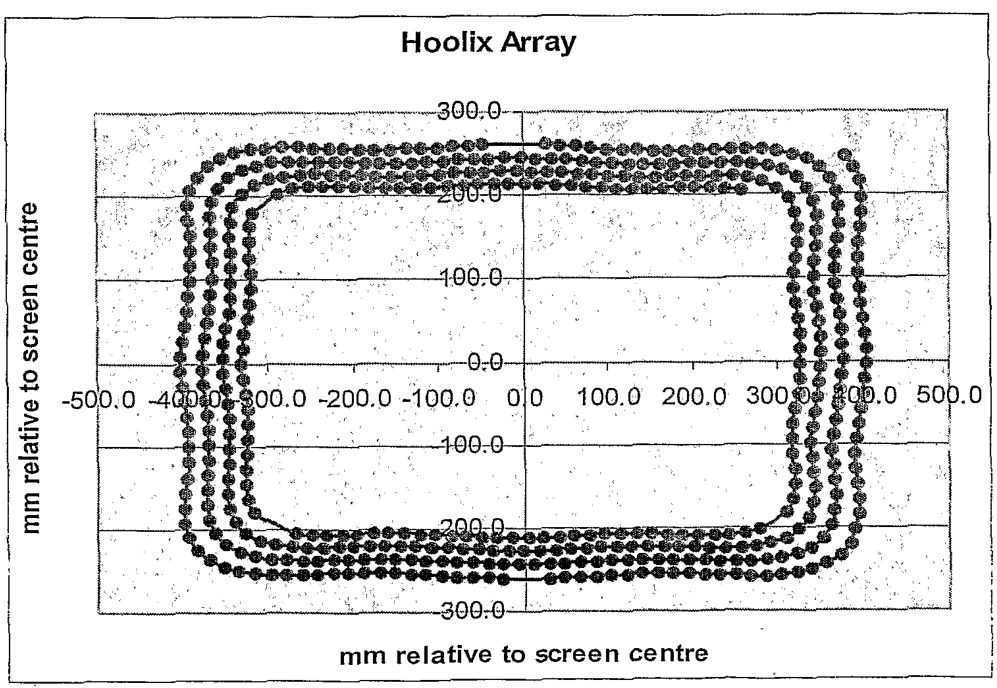

Hoolix Array
300.0
200.0
100.0
0.0
-500.0
-400.0
-300.0
-200.0
-100.0
0.0
100.0
200.0
300.0
400.0
500.0
-100.0
-200.0
-300.0
mm relative to screen centre
mm relative to screen centre

FIG. 3.

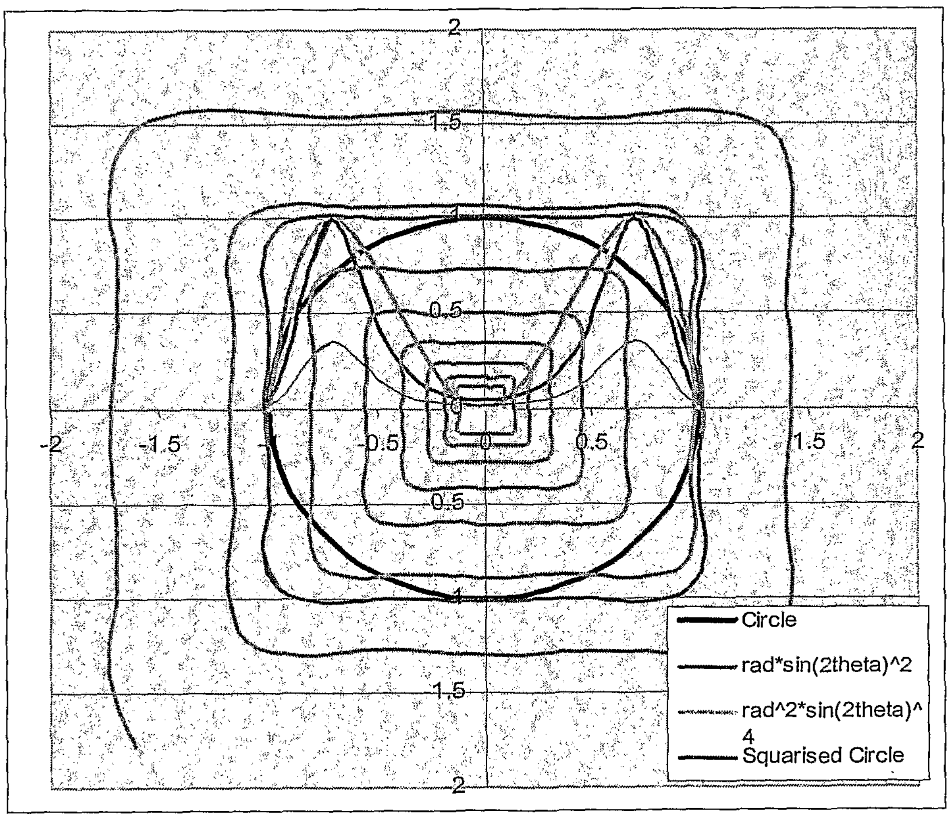

2
1.5
1
0.5
0
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
0.5
1
1.5
2
Circle
rad*sin(2theta)^2
rad^2*sin(2theta)^4
Squarised Circle

FIG. 4.

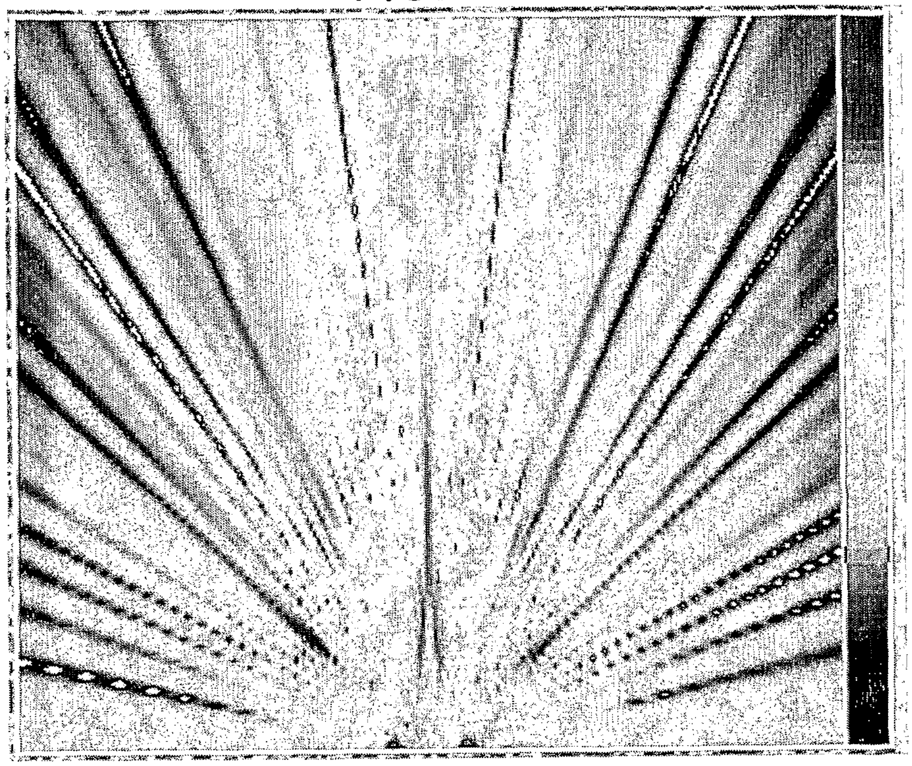


FIG. 5.

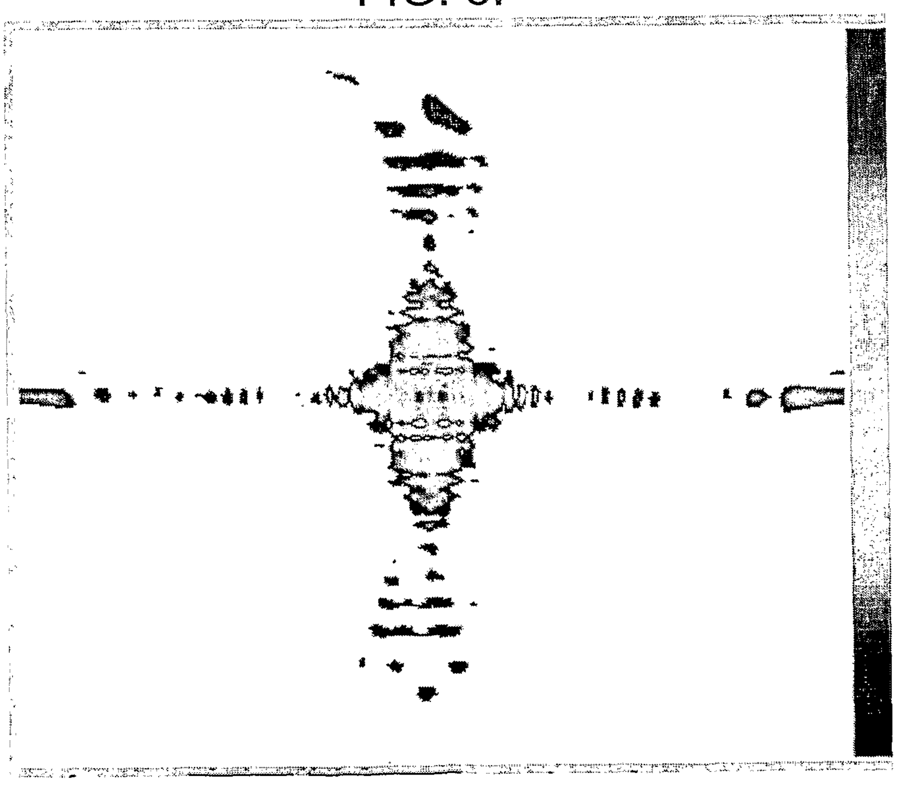


FIG. 6.

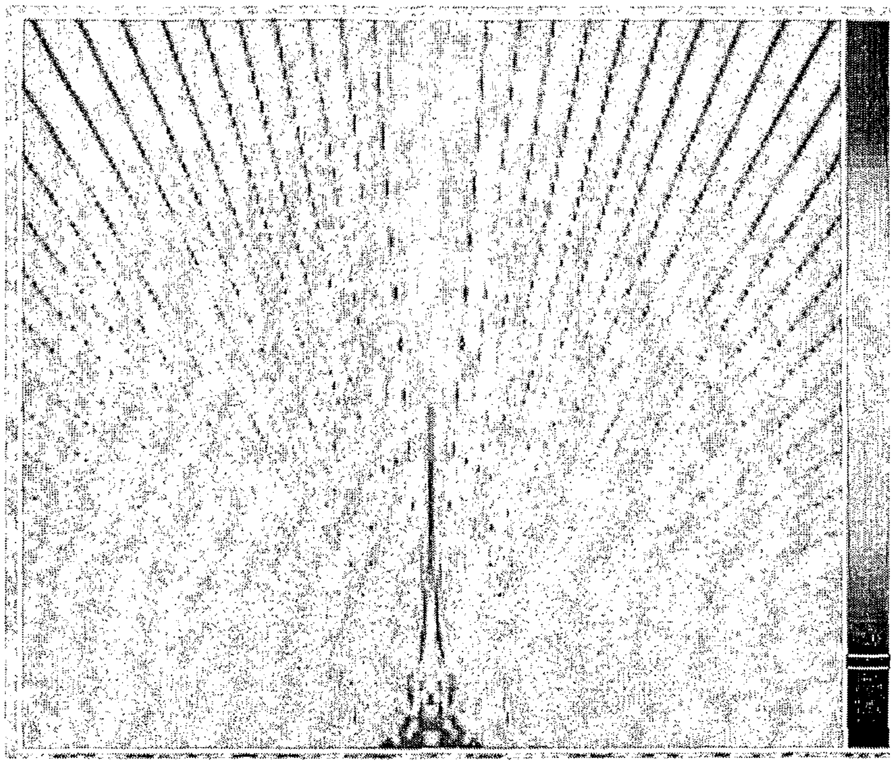
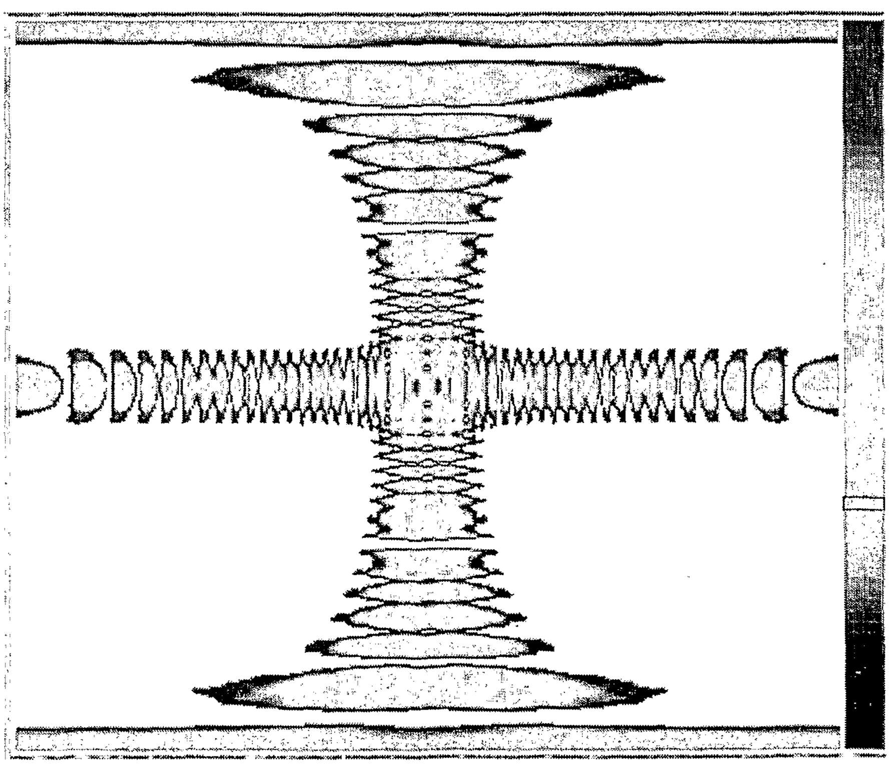


FIG. 7.



INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB2005/003528

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04R1/40 H04R3/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0 323 110 A (MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD) 5 July 1989 (1989-07-05)	1,2,8-12
A	column 3, line 3 - line 45 figure 4	3-7, 13-16
Y	WO 2004/075601 A (1...LIMITED; HOOLEY, ANTHONY; LENEL, URSULA, RUTH; GOUDIE, ANGUS, GAVI) 2 September 2004 (2004-09-02)	1,2,8-12
A	page 8, line 1 - page 10, line 4 page 17, line 17 - page 28, line 6 page 33, line 7 - page 36, line 8	3-7, 13-16
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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 November 2005	17/11/2005

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Coda, R

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB2005/003528

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Form PCT/ISA/210 (continuation of second sheet) (January 2004)

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